FINITE ELEMENT ANALYSIS AND DESIGN OF METAL STRUCTURES

EHAB ELLOBODY | RAN FENG | BEN YOUNG

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CHAPTER 1

Introduction

1.1. GENERAL REMARKS

Most of finite element books available in the literature, e.g. Refs [1.1–1.7], deal with explanation of finite element method as a widely used numerical technique for solving problems in engineering and mathematical physics. The books mentioned in Refs [1.1–1.7] were written to provide basic learning tools for students in civil and mechanical engineering. The aforementioned books highlighted the general principles of finite element method and the application of method to solve practical problems. Numerous books are also available in the literature, as examples in Refs [1.8–1.26], addressing the behavior and design of metal structures. The books mentioned in Refs [1.8–1.26] have detailed the analysis and design of metal structural elements considering different design approaches. However, up-to-date, there is a dearth in the books that detail and highlight the implementation of finite element method in analyzing metal structures. Extensive numerical investigations using finite element method were presented in the literature as research papers on metal columns, beams, beam columns, and connections. However, detailed books that discuss the general steps of finite element method specifically as a complete work on metal structures and connections are rarely found in the literature, leading to the work presented in this book.

There are many problems and issues associated with modeling of metal structures in the literature that students, researchers, designers, and academics need to address. This book provides a collective material for the use of finite element method in understanding the behavior and structural performance of metal structures. Current design rules and specifications of metal structures are mainly based on experimental investigations, which are costly and time consuming. Hence, extensive numerical investigations were performed in the literature to generate more data, fill in the gaps, and compensate the lack of data. This book also highlights the use of finite element methods to improve and propose more accurate design guides for metal structures, which is rarely found in the literature. The book contains examples for finite element models developed for

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different metal structures as well as worked design examples for metal structures. The authors hope that this book will provide the necessary material for all interested researchers in the field of metal structures. The book can also act as a useful teaching tool and help beginners in the field of finite element analysis of metal structures. The book can provide a robust approach for finite element analysis of metal structures that can be understood by undergraduate and postgraduate students.

The book consists of eight well-designed chapters covering necessary topics related to finite element analysis and design of metal structures. Chapter 1 provides a general background for the types of metal structures, mainly on columns, beams, and tubular connections. The three topics present the main structural components that form any metal frame, building, or construction. Detailing the analysis of these components would enable understanding the overall structural behavior of different metal structures. The chapter also gives a brief review of the role of experimental investigations as the basis for finite element analysis. Finally, the chapter highlights the importance of finite element modeling and current design codes for understanding the structural performance of metal structures.

Chapter 2 provides a simplified review of general steps of finite element analysis of metal structures. The chapter enables beginners to understand the fundamentals of finite element analysis and modeling of complicated structural behavior of metals. The chapter also includes how to divide a metal structural element into finite elements and how to select the best type of finite elements to represent the overall structural element. The chapter provides a brief review of the selection of displacement functions and definition of strain—displacement and stress—strain relationships. In addition, Chapter 2 also presents a brief review of the formation of element stiffness matrices and equations, the assemblage of these equations, and how the assembled equations are solved for unknowns.

Chapter 3 focuses on finite element modeling of metal structures and details the choice of element type and mesh size that can accurately simulate the complicated behavior of different metal structural elements. The chapter details how the nonlinear material behavior can be efficiently modeled and how the initial local and overall geometric imperfections were incorporated in the finite element analysis. Chapter 3 also details modeling of different loading and boundary conditions commonly applied to metal structures. The chapter focuses on the finite element modeling using any software or finite element package, as an example in this book, the use of ABAQUS [1.27] software in finite element modeling.

Chapter 4 extends the information covered in Chapter 3 to explain and detail the commonly used linear and nonlinear analyses in finite element modeling of metal structures. The chapter also explains the analyses generally used in any software and details as an example the linear and nonlinear analyses used by ABAQUS [1.27]. The chapter also contains a brief survey and background of the linear and nonlinear analyses. It details the linear eigenvalue used to model initial local and overall geometric imperfections. The nonlinear material and geometrical analyses related to metal structures are also highlighted in Chapter 4. In addition, the chapter also gives a detailed explanation for the RIKS method used in ABAQUS [1.27] that can accurately model the collapse behavior of metal structural elements.

Chapters 5–7 give illustrative examples for finite element models developed to understand the structural behavior of metal columns, beams, and tubular connections, respectively. These chapters start by a brief introduction to the contents as well as a detailed review on previous investigations on the subject. The chapters also detail the developed finite element models and the results obtained. The presented examples show the effectiveness of finite element models in providing detailed data that complement experimental data in the field. The results are discussed to show the significance of the finite element models in predicting the structural response of different metal structural elements.

Finally, Chapter 8 presents design examples for metal tubular connections. The chapter starts by a brief introduction to the contents. The chapter also details the finite element models developed for the presented metal tubular connections. The design rules specified in current codes of practice for the presented connections are also discussed and detailed in this chapter. At the end of the chapter, comparisons between design predictions and finite element results are presented.

1.2. TYPES OF METAL STRUCTURES

The main objective of this book is to provide a complete piece of work regarding finite element analysis of metal structures. Hence, it is decided to highlight finite element modeling of main metal structural elements, which are columns, beams, and tubular connections. The metal structures cover structures that may be constructed from any metal such as carbon steel, cold-formed steel, stainless steel, aluminum, or any other metals. The aforementioned materials have different stress–strain curves, yield, and post-yield criteria. Figure 1.1 shows examples of stress–strain curves

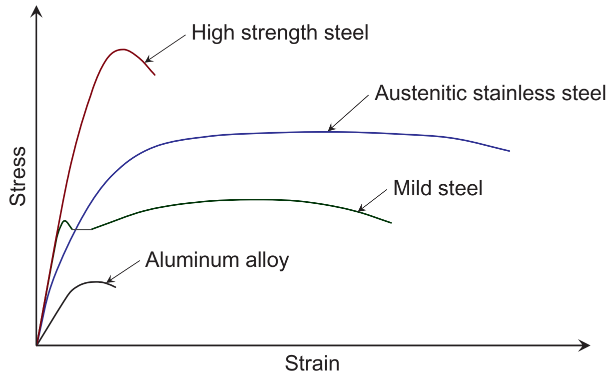

Figure 1.1 Stress–strain curves of different metals.

for some of the aforementioned metals. For example, the stress–strain curves of stainless steel, high strength steel, and aluminum have a rounded behavior with no yield plateau compared with the stress–strain curves of carbon steel as shown in Figure 1.1. Hence, the structural performance of these metal columns, beams, and tubular connections will be different from that of carbon steel. This book provides a detailed description on finite element analysis of columns, beams, and tubular connections that are composed of any metallic materials. It should also be noted that the structural performance of different metals varies at ambient temperature as well as at elevated temperatures. However, this book only focuses on analyzing metal structures at ambient temperature. Furthermore, the finite element analysis of metal structures depends on the type of applied loads. For example, the structural performance of metal structural elements subjected to static loads differs from that subjected to seismic, cyclic, dynamic loads or any other types of loads. However, this book details the finite element analysis of metal structures subjected to static loads or any other loads that can be replaced by equivalent static loads.

Looking at the metal columns analyzed using the finite element method in this book, the columns can be individual metal columns, which represent the cases of metal column test specimens. On the other hand, the columns investigated can be parts of structural metal frames or trusses. The columns presented in this book can have different end boundary conditions that vary from free to fixed-ended columns, different lengths, and different cross sections constructed from hot-rolled, cold-formed, or welded built-up sections. Figure 1.2 shows examples of different column cross sections that can be investigated using finite element

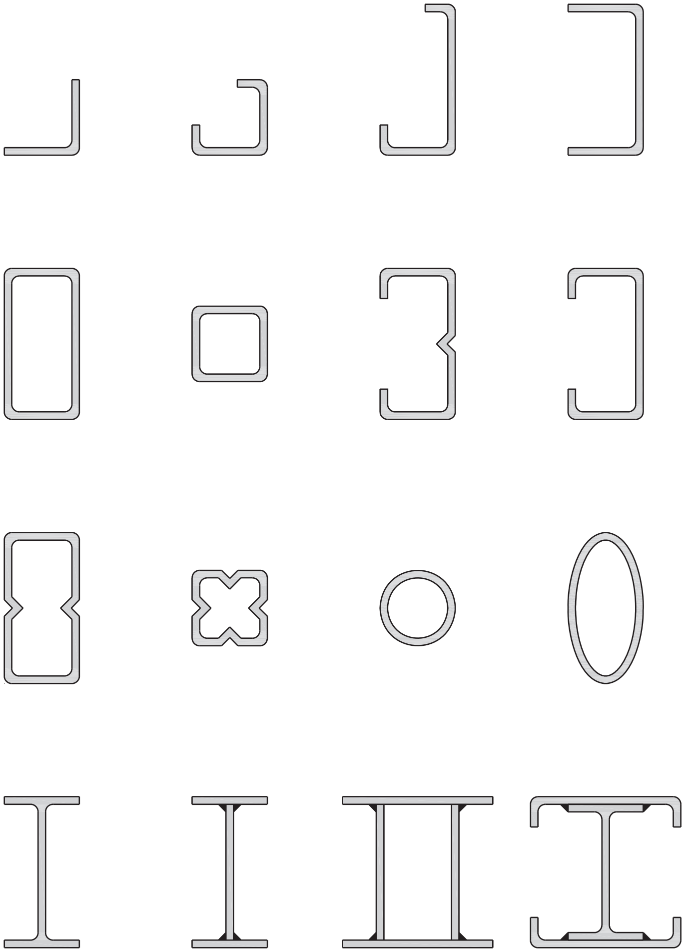

Figure 1.2 Cross sections of some metal columns covered in this book.

analysis covered in this book. The examples of cross sections are square, rectangular, circular, I-shaped, solid, hollow, stiffened, and unstiffened sections.

The metal beams presented in this book using the finite element method can also form single metal beams such as metal beam test specimens. Alternatively, the beams can be part of floor beams used in structural metal frames or framed trusses. Therefore, the beams investigated also can have different end boundary conditions that vary from free to fixed support with or without rigid and semi-rigid internal and end supports. The beams investigated can have different lengths and different

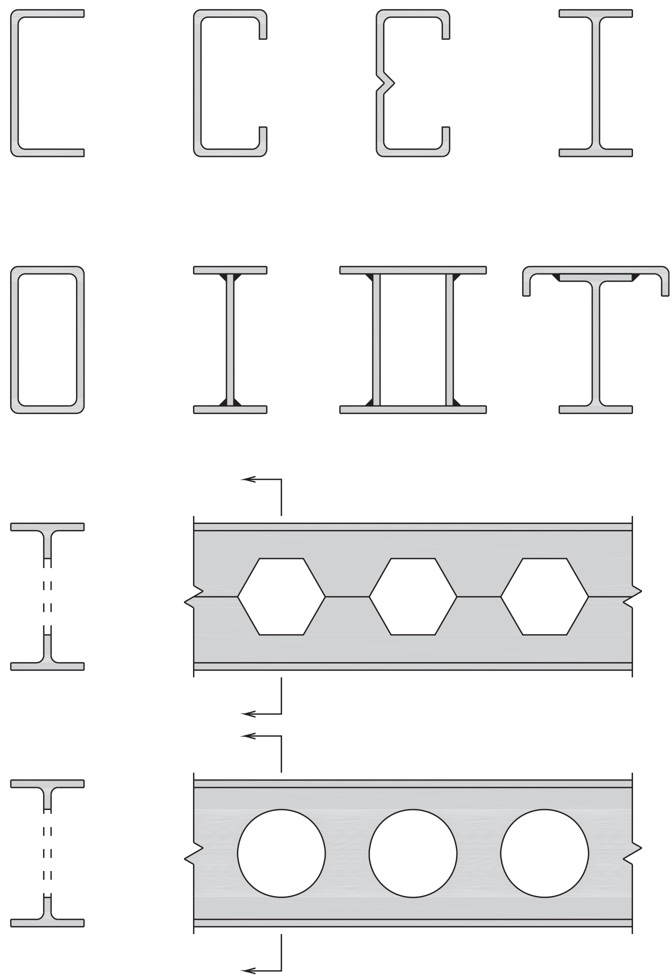

Figure 1.3 Cross sections of some metal beams covered in this book.

cross sections constructed from hot-rolled, cold-formed, or welded built-up sections. Figure 1.3 shows examples of different beam cross sections that can be investigated using finite element analysis. The examples of cross sections include I-shaped, channel, hollow, castellated, cellular, stiffened, and unstiffened sections, as shown in Figure 1.3.

Investigating the interaction between metal columns and beams using finite element analysis is also covered in this book. The beams and columns are the main supporting elements of any metal frames and trusses. By highlighting the structural performance of metal tubular connections,